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ABSTRACT

This paper describes the development of a sixth-grade "Matter and Molecules" unit using a new curriculum development model based on conceptual change research, the field testing of this unit in 15 classrooms and the field test results. The development process and the resulting unit are contrasted with the unit's predecessor, the "Models of Matter" unit in a commercial sixth-grade text. The development process was based on an extensive program of research on student conceptions and classroom teaching using preclinical interviews, pretests, classroom observations, journals by collaborating teachers, postclinical interviews, and posttests. The development procedures also included a careful content analysis and extensive interaction with collaborating teachers who were part of the development team. It is argued that the procedures described in this paper constitute a workable alternative to present curriculum development procedures and that the alternative procedures are superior in two respects. First, these procedures make use of the methods and findings of recent research on teaching and on students' scientific cognition. Second, posttest results and interviews with teachers indicate that the new unit was demonstrably superior to its commercial predecessor in terms of the students' conceptual understanding and the teachers' professional satisfaction. (Author/CW)

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Glenn D. Berkheimer, Charles W. Anderson,
and Theron D. Blakeslee

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## Abstract

This paper describes the development of a sixth-grade "Matter and Molecules" unit using a new curriculum development model based on conceptual change research, the fieldtesting of this unit in 15 classrooms and the fieldtesting results. In the paper, the development process and the resulting unit are contrasted with the unit's commercial predecessor, the "Models of Matter" unit in the Houghton Mifflin Science sixth-grade text (Berger, Berkheimer, Neuberger, & Lewis, 1979).

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We argue that the procedures described in this paper constitute a workable alternative to present curriculum development procedures and that the alternative procedures are superior in two respects. First, these procedures make use of the methods and findings of recent research on teaching and on students' scientific cognition. Second, posttest results and interviews with teachers indicate that the new unit was demonstrably superior to its commercial predecessor in terms of students' conceptual understanding and teachers' professional satisfaction.

# USING A NEW MODEL OF CURRICULUM DEVELOPMENT TO WRITE A MATTER AND MOLECULES TEACHING UNIT

Glenn D. Berkheimer, Charles W. Anderson, and Theron D. Blakeslee[1]

This paper is one of three that focuses on the development of a middle-school science unit about the kinetic molecular theory (the idea that all matter is composed of atoms or molecules and that these particles are constantly in motion) and its application to physical changes in matter, including expansion and contraction, dissolving, and changes of state. The title of the unit in its final form is "Matter and Molecules" (Berkheimer, Anderson, Lee, & Blakeslee, 1988; Berkheimer, Anderson, & Blakeslee, 1988). The second paper (Berkheimer, Anderson, and Spees, 1990) focuses on the curricular problems involved in designing this unit. A third paper (Lee, Eichinger, Anderson, Berkheimer, & Blakeslee, in press) describes findings from research on student conceptions associated with the project and reports on student achievement using the unit. This paper describes the development process itself and the instructional strategies that were built into the unit.

Much of our description of the development process will be built around the contrast between this unit and its commercial predecessor, the "Models of Matter" unit in the Houghton Mifflin Science sixth-grade text (Berger, Berkheimer, Neuberger, & Lewis, 1979). (The senior author of this paper was also the primary author of the "Models of Matter" unit.) We make this contrast in order to illustrate what we see as the serious deficiencies in the

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[1]Glenn Berkheimer, a professor of teacher education at Michigan State University, and a senior researcher with the Institute for Research on Teaching, was the coordinator of the Educational Systems to Increase Student Achievement Project. Charles Anderson, an IRT senior researcher with the project, is associate professor of teacher education at MSU. Theron Blakeslee, a former project research assistant, is a science specialist for the Michigan State Department of Education.

curriculum development processes that currently predominate among commercial and National Science Foundation-supported projects and to show that reasonable and practical improvements in the process are possible. In particular, we will illustrate how the methods and results of current research on children's scientific conceptions can be incorporated into the curriculum development process.

Although most of this paper focuses on differences between the two units, the comparison is instructive because the units are similar in a number of ways. One similarity is that the units share the same general goal: to help students understand the kinetic molecular theory and use it to explain physical phenomena. Both units are also designed to be used at the same grade level (around sixth) and to be similar in length (about 9-10 weeks). Furthermore, both units are designed to work within the constraints characteristic of U.S. public education as it currently exists, including the following:

1. A diverse student population including substantial numbers of students who are at risk due to social, cultural, or economic factors
2. Lack of access to well-equipped laboratories or computers for many classrooms
3. A prevalence of teachers who do not have strong backgrounds in science
4. A lack of resources for sustained programs of inservice teacher education

These were the conditions that prevailed in the 15 classrooms where the "Matter and Molecules" unit was developed and field-tested. These classrooms were all in a middle-sized midwestern industrial city surrounded by more affluent suburbs. The students in these classrooms were 60% Caucasian, 25% Black, and 15% other ethnic minorities, including Hispanics and immigrants from a variety of East Asian nations. Only one of the teachers with whom we worked had a degree in science. The others were mostly elementary teachers who had

moved up to the middle school when the district had changed from a junior high school-based system. Inservice training was limited to a single full-day workshop for most of the teachers. Neither unit made use of specialized laboratory equipment or information-processing technology.

We have chosen to contrast the development processes for the two units and their resulting products by focusing on sections of the two units that are quite similar in terms of conceptual content and classroom activities. Both units contain a Lesson Cluster (a sequence of 3-6 lessons) focusing on thermal expansion in solids, liquids, and gases. Furthermore, the activity focusing on thermal expansion of gases is the same in both units; it is an activity that we have labeled the "dancing dime."

In the dancing dime activity, students observe a dime that has been placed over the moistened opening of a chilled empty quart soda bottle. As they warm the soda bottle with their hands, they see the dime begin to "dance," to move up and down as air escapes from the soda bottle. The basic goal of the activity is the same in both units: Students are to explain that the "dancing" results from thermal expansion of the air in the bottle and to explain thermal expansion in terms of molecular motion--as the temperature of the air rises, the molecules of air move faster and therefore bounce farther apart.

Appendices A and B contain the dancing dime activity in both its original commercial version and its revised version. It is clear from a comparison of the two versions that although the activity and its basic purpose have remained unchanged, the instructional approach and the information provided in the teacher's guide have been substantially altered. The purpose of this paper is to explain the reasons of those (and many other) alterations and to describe the process that led to the development of the new unit.

## Comparing the Development Processes

In broad outline, the development processes for each unit can be described as consisting of three general stages. First, statements about goals and some initial ideas about instructional activities were developed. Second, draft versions of the units were outlined and written. Finally, the draft versions were field-tested and the results of the fieldtesting were used to revise the units and develop a final draft. The nature of the curriculum development activities and the products of those activities, however, were substantially different for the two units at each stage in the development process. These contrasts are described in detail below.

### Developing Goal Statements

Descriptions of goals or intended learning outcomes that were detailed enough to guide the writing process were developed early in the evolution of each unit. The procedures for developing those statements of intended learning outcomes and the nature of the goal statements produced are described and contrasted below.

Developing goal statements for "Models of Matter". Like all curriculum developers, the authors of Houghton Mifflin Science began with certain assumptions about the nature of the knowledge that students would gain from science instruction. Some of these assumptions were explicit; others were consequences of unexamined beliefs or of the organizational frameworks that the authors chose for their statements about intended learning outcomes. The assumptions that guided the authors of Houghton Mifflin Science had several sources. The most important of these was probably the Science Curriculum Improvement Study (SCIS) program (Karplus, and associates, 1971), for which the senior author of this paper was a trial center coordinator. The conceptual development of the

"Models of Matter" unit was also guided in part by the work of Milton Pella (Pella & Carey, 1968). Finally, the authors wished to include in the program science processes like those described in the Science . . . A Process Approach (SAPA) program (American Association for the Advancement of Science, 1968).[2]

In the initial stages of development, a conceptual framework and a set of behavioral objectives were written and a tentative list of possible instructional activities was suggested. An early version of these lists is presented in Figure 1. (Note that the initial plans did not include the thermal expansion of gases in this lesson cluster, but was added to the list of possible activities.)

Although the activities afforded opportunities to practice science process skills, the process skills did not play an explicit role in the early development of goal statements for the unit. The verbs of some of the behavioral objectives (called "behavioral patterns" in Figure 1) connote process skills, but this is not true for all the objectives. The relationship with process skills is particularly problematic for the key objective of this lesson cluster, which in its final form was to "explain the expansion and contraction of solids, liquids, and gases in terms of the small particle model."

Although the authors struggled to develop sequences of objectives and activities that provided for the coherent development of both content knowledge and process skills, they were never entirely successful in sequencing the process skills. Their eventual resolution to the problem of explicating the

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[2]The SAPA processes were the basic processes--observing, using space/time relationships, classifying, using numbers, measuring, communicating, predicting and inferring, and the integrated processes--formulating hypotheses, defining operationally, controlling variables and interpreting date and experimenting. The integrated processes were emphasized in Grades 4-6 and the basic processes K-6.

Figure 1: Proposed Rationale, Concepts, Objectives, and Activities for Lesson Cluster B-1

Part B Applying The Small Particle Model

The small particle model is reviewed and applied to a variety of situations. In cluster B-1 students explain expansion contraction, and the resulting temperature of mixing warm and cold water in terms of the small particle model. Students in cluster B-2 attempt to explain surface phenomena in terms of the small particle model. Although students have studied solids, liquids, and gases earlier in the program, they are challenged in cluster B-3 to explain the change of phase in terms of the small particle model.

Cluster B-1 Applying the Small Particl Model to Conductive Systems

In cluster B-1 evidence involving conduction systems is explained in terms of the small particle model. Students are challenged to use the small particle model in explaining the expansion and contraction of solids and liquids; the action of a thermometer; and the result of mixing warm and cool water.

Although alternative models may be used by the students to explain the evidence, they should be encouraged to develop their skill in explaining and thinking in terms of the small particle model.

Concepts: Particles of matter move faster when the matter is heated. Particles of matter usually move further apart when the matter is heated.

Behavioral Patterns

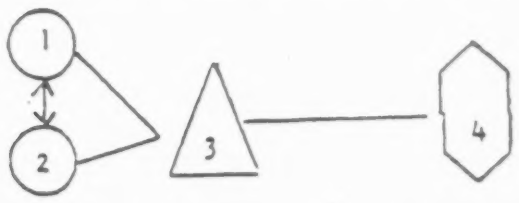
The student...

--uses the small particle model to explain expansion and contraction.

--explains the action of a thermometer using the small particle model

--analyzes the evidence obtained from mixing water of various temperatures and explains this evidence in terms of the small particle model.

II - B Expansion - Contraction and the Small Particle Theory
1. Ball and Ring
2. Expansion and Contraction of Hacksaw Blades.
3. Expansion and Contraction of Liquids.
T-89 4. Expansion and Contraction of Gases.



relationship between concepts and process skills is illustrated in Table 1. The SAPA list of 13 process skills was condensed into four general categories in part because, in the words of one of the authors, "then we can slop it in." What "slopping it in" meant in practice is illustrated by the distribution of the key "explain" objectives in the Concept/Process Chart (Table 1). Some of these objectives are listed under "Observing and Describing," others under "Investigating and Manipulating," and still others under "Generalizing and Applying."

The authors' inability to develop an adequate account of the relationship between concepts and processes was not unique to Houghton Mifflin Science. In fact, we do not believe that any program has ever developed an adequate framework for relating concepts and processes because there are fundamental philosophical and theoretical flaws in the conception of "science process skills." (For an excellent discussion of these flaws, see Millar and Driver, 1987.) Thus the failure of the authors to develop a conceptually tight Concept/Process Chart was foreordained by their assumption that the content of the unit consisted of separable "concepts" and "process skills."

Developing goal statements for "Matter and Molecules." Development of statements of intended learning outcomes for the "Matter and Molecules" unit began with two basic convictions. First, we believed that the conceptual content of the earlier "Models of Matter" unit was critically important for middle school students to understand (cf., Berkheimer, Anderson, & Spees, 1990). Second, we believed that the unit could be made much more effective if we incorporated into the development process a set of intellectual tools and techniques that were not available to curriculum developers of the 1960s and 1970s: the tools and techniques developed through research on cognitive

# Concept/Process Chart

| Key Processes \ Key Concepts | ***More Than One Model*** | ***The Small Particle Model*** | ***Applying Models*** |
|---|---|---|---|
| | Systems and interactions not directly observable can be modeled. Four different models are used to explore mixing systems. Of the four, the small particle model is the most successful. | All matter consists of small particles that are in constant motion. The particles of matter move faster when heated. In going from solid to liquid to gas the particles of matter move more freely and become farther apart. Particles of matter attract each other. | The small particle model explains the water cycle, including evaporation, condensation, and convection, and the interaction of certain gases with liquids. Scientific models are tested and, if necessary, changed to meet the needs of new evidence. |
| **Observing and Describing** | Develops models of a hidden object and a hidden structure from indirect evidence. Identifies the relative success of models. Gives examples of mixtures. Explains mixing phenomena in terms of several models. | Explains a variety of mixing phenomena in terms of the small particle model. Explains expansion and contraction in solids, liquids, and gases in terms of the small particle model. Explains phase changes, i.e., evaporation, condensation, and melting, in terms of the small particle model. Describes the forces acting on particles in liquids. Explains surface tension in terms of the small particle model. | Explains the effects of temperature and depth on mixing in terms of the small particle model. Explains convection, evaporation, condensation, and the water cycle in terms of the small particle model. Explains liquid layering in terms of the small particle model. Explains the interaction of a gas and a liquid in terms of the small particle model. Explains how experimental evidence can lead to new models. |
| **Investigating and Manipulating** | Assembles physical models to make inferences about hidden objects and systems. Carries out mixing experiments to test models. Explains color separation by paper chromatography in terms of several mixing models. | Carries out a variety of mixing experiments to evaluate small particle model. Demonstrates expansion and contraction of solids, liquids, and gases to evaluate small particle model. Demonstrates properties of gases and explains in terms of small particle model. Carries out surface tension experiments to evaluate small particle model. | Carries out convection, evaporation, condensation, and water cycle simulation experiments to evaluate small particle model. Demonstrates the interaction of a gas and a liquid at different temperatures and explains in terms of the small particle model. Tests for the presence of carbon dioxide. Identifies carbon dioxide in exhaled breath. Tests a model of falling objects. |
| **Organizing and Quantifying** | | | |
| **Generalizing and Applying** | Develops models of a circuit puzzle to explain observed data. Predicts events based on models. Predicts properties of mixtures. Predicts mixing phenomena in terms of several models. Tests mixing models under varying conditions. Evaluates how well a model explains the mixing of paints. | Determines the effect of temperature on mixing and explains in terms of the small particle model. Explains expansion and contraction of solids in terms of the small particle model. Explains evaporation of water in terms of energy transfer and the small particle model. Evaluates wetting ability of plain and soapy water in terms of the small particle model. | Applies the small particle model to convection currents, evaporation, condensation, the water cycle, and the formation of rain. Explains the movement of particles through a membrane in terms of the small particle model. Makes and tests predictions about falling objects. Describes the importance of being able to predict earthquakes. |

structure and conceptual change (cf., Driver, Guesne, & Tiberghien, 1985; Gentner & Stevens, 1983).

In order to use conceptual change research, we had to reconceptualize both the nature of the intended learning outcomes and the process by which they were developed. The nature of our goal statements needed to be altered in two ways. First, we were determined to find some resolution of the content-process dilemma described above. Second, we wished to describe our goals in terms that recognized the complex ways in which students must construct new knowledge from their prior knowledge and their experiences in class. That is, instead of simply describing the knowledge that students were to acquire, we wanted our goal statements to describe student learning as a process of conceptual change.

One implication of this conceptual change orientation was that we needed to collect information that had played no explicit role in the development of the "Models of Matter" unit: information about students' prior understanding of the nature of matter and of physical changes in matter. Thus development of the "Matter and Molecules" unit began with an extensive program of research into student conceptions. Data about student conceptions were collected in two ways: through pretests and clinical interviews.

Pretests were designed to elicit students' conceptions about the nature and constitution of matter and about how physical changes in matter take place. The tests were developed through an iterative strategy involving development, pilot testing, and refinement of test items and analytical frameworks. This process has been described elsewhere (Anderson & Smith, 1983; Eichinger & Lee, 1988). The pretests were administered to all students in the classrooms of four collaborating teachers (teachers who worked as members of the project staff).

The clinical interviews were administered to 24 target students, eight of whom had been judged by the collaborating teachers to be "high achievers," eight of whom were "medium achievers," and eight of whom were "low achievers." The clinical interviews called on students to engage in a series of tasks that were similar to, but not the same as, instructional activities in the "Models of Matter" unit. The students were observed and questioned closely about their thinking as they engaged in the tasks. For example, the task most closely related to the dancing dime activity called on students to explain why a balloon that is stretched over the mouth of a cold soda bottle inflates as the bottle is warmed.

The students' responses to the pretest and clinical interviews revealed many conceptual problems that the Houghton Mifflin Science authors had not suspected. Some of these problems had nothing to do with students' ideas about molecules. For example, some students tried to explain the expansion of the balloon without referring to air at all; they focused instead on what was happening to the bottle and the balloon. Other students did not believe that substances expand when heated; they believed that heat made things "shrivel up." Few students saw a request to "explain" a phenomenon as calling for a reductionistic reference to subsystems or molecules (cf., Hesse & Anderson, 1988; Solomon, 1983); they tried instead to repeat what they had observed or to relate their observations to familiar events in their everyday lives.

When students were explicitly asked to discuss their ideas about molecules or the microscopic constitution of matter, what they said bore little resemblance to the kinetic molecular theory as scientists understand it. Even after instruction, many students viewed molecules of a substance as being suspended in the substance, like blueberries in a muffin, rather than as being the substance itself. They often believed molecules to be much larger than they

actually are; they rarely understood molecules to be constantly in motion; and they tended to explain observable phenomena by suggesting that molecules went through the same kinds of changes as the observable substances. For example, some students explained thermal expansion by saying that the molecules expanded, rather than discussing molecular motion and the distances between molecules. In general, the tests and clinical interviews revealed that apparently simple tasks like explaining the "dancing" dime were in fact conceptually complex and difficult for sixth-grade students. They also revealed a great deal of specific information about students' ways of thinking and performance on specific tasks.

We wished to do more, however, than simply generate insights about students' conceptions of matter and molecules. We wished to use those data to develop statements about intended learning outcomes that could guide the process of curriculum development. Developing these descriptions of intended learning outcomes occupied several months at the beginning of the project. In their final form, they included what we call a Tasks by Conceptions Chart (Table 2) and a Naive Conceptions/Goal Conceptions of Matter and Molecules Chart (Table 3).

There are some superficial similarities between Table 2 and Table 3. The differences, however, are far more important. The concepts and processes on Table 3 were conceived of as two different kinds of knowledge. In contrast, all internally held knowledge, both conceptual and procedural, fits in the category of conceptions in the Table 2 chart. The tasks are descriptions of the actions or activities that students are able to engage in by using their knowledge in social contexts. It may be useful to consider an analogy between conceptions and tasks and the biological concepts of structure and function. Just as biological systems have structures (e.g., the organs of the human body)

TABLE 2

Tasks by Conceptions Chart for Kinetic Molecular Theory

| Tasks | | Description | Macroscopic Conceptions | | | | | | | | Molecular Conceptions | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 1. Matter vs. non-matter | a. describe | | X | X | | | | | | | X | X | | | | | | | | | |
| | b. contrast | | | | | | | | | | | | | | | | | | | | |
| | c. classify examples | | X | | | X | | | | | | | | | | | | | | | |
| 2. Compare/ contrast states of matter | a. composition | | | | | X | | | | | X | X | X | | | | | | | | |
| | b. dif. betwn. s/l/g | | | | | | | | | | X | | X | X | | | | X | X | | |
| | c. examples of s/l/g | | | | | X | | | | | | | | | | | | | | | |
| 3. Explain dissolving | a. kool-aid | bag does not break | | X | | | | | | | X | X | X | X | X | | | | | | |
| | b. sugar | sugar disappears | | X | | | | | | | X | X | X | X | X | | | | | | |
| | c. hot/cold water | | | | | | | | | | | | | | | X | | | | | |
| 4. Explain thermal expansion | a. balloon & bottle | no air leaks out | | | X | | | | | | X | | X | X | | X | X | X | | | |
| | b. ball & ring | ball does not melt | | | X | | | | | | X | | X | X | | X | X | | | | |
| 5. Explain expansion & compression of gases | a. syringe | no air leaks out | | | | | X | X | | | X | | | | | | | X | | | |
| | b. syringe: air vs. water | | | | | | | | | | X | | | | | | | X | X | | |
| | c. bike tire (t) | no air leaks out | | | | | X | X | | | X | | | | | | | X | | | |

| Tasks | | | Macroscopic Conceptions | | | | | | | | Molecular Conceptions | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Description | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
| 6. Explain melting and freezing | a. ice melting | | | X | | | | | | | X | | X | X | | X | X | | X | X | |
| | b. water freezing (t) | | | | | | | | | | | | X | X | | X | X | | X | X | |
| 7. Explain evaporation & boiling | a. steam | | | X | | | | | X | | X | X | X | | | X | X | | X | X | X |
| | b. bubbles | bubbles pop at surface | | | | | | | | | | | | | | | | | | | |
| | c. alcohol | alcohol disappears | | X | | | | | X | | X | X | X | X | | | | | X | | X |
| | d. cup of water (t) | | | X | | | | | X | | X | X | X | X | | | | | X | | X |
| 8. Explain smells | a. perfume | | | X | | X | X | | | | X | X | X | X | | | | | X | | X |
| | b. onion (t) | | | X | | X | X | | | | X | X | X | X | | | | | X | | X |
| 9. Explain condensation | a. pop can (t) | condensate is water and | | X | | | | | X | X | X | | | | | X | X | | X | X | X |
| | b. ice water cup | water does not leak through | | X | | | | | X | X | X | | | | | X | X | | X | X | X |
| | c. glass plate | | | X | | | | | X | X | X | | | | | X | X | | X | X | X |
| | d. car window (t) | fog is water, on inside of windows | | X | | | | | X | X | X | | | | | X | X | | X | X | X |

TABLE 3 4/03/87

Student Conceptions of Matter and Molecules

| Issue | Goal Conception | Typical Naive Conception |
|---|---|---|
| **Macroscopic level: Conceptions about observable substances and phenomena** | | |
| 1. Definition of matter | 1.a. Solids, liquids, and gases are matter, other things (e.g., heat, light) are not. | 1.a. Gases and non-matter often incorrectly classified. |
| | b. Matter takes up space, non-matter does not. | b. Classification based on other properties (e.g., matter is some-thing you can see or feel). |
| 2. Conservation of matter | 2. Matter is conserved in all physical changes. | 2. Matter not always conserved especially in changes involving gases. Words like "dissolve" and "evaporate" sometimes used as synonyms for "disappear." |
| 3. Thermal expansion | 3. Substances expand when heated. | 3. Substances may "shrivel up" when heated; expansion of gases explained in terms of movement of air. |
| 4. Nature of smells | 4. Smells are gases, therefore matter, made of molecules, etc. | 4. Smells considered ephemeral, not really matter. |
| 5. Distribution of gases in space | 5. Gases spread evenly through the spaces they occupy. | 5. Distribution of gases is uneven before or after expansion or compression. |
| 6. Compression of gases | 6. Gases can be compressed. | 6. Gases move from one region to another; no notion of compression or expansion. |
| 7. Water vapor in air | 7. Air contains invisible water vapor (humidity). | 7. Water in air is visible (e.g., fog, "steam"). |
| 8. Condensation | 8. Water vapor in air condenses on cold objects. | 8. Condensate is "fog" or "breath"; or is formed by a reaction between heat and cold. |

| | | | | | |
|---|---|---|---|---|---|
| 9. | Molecular constitution of matter | 9. | All matter is made of molecules, non-matter is not. | 9. | Material substances not described as molecular; non-matter described as molecules (e.g.,"heat molecules"); molecules are <u>in</u> substances. |
| 10. | Size of molecules | 10. | Molecules are too small to see, even with a microscope. | 10. | Molecules may be comparable in size to cells, dust specks, etc. |
| 11. | Constant motion | 11. | All molecules are constantly moving. | 11. | Molecules may sometimes be still, especially in solids. |
| 12. | Visibility of molecular motion | 12. | Molecular motion continues independently of observable movement. | 12. | Molecules simply share in observable movements of substances (e.g., convection currents); Molecules move in gases and liquids, not in solids. |
| 13. | Molecular explanation of dissolving | 13. | Molecules of solute break away and mix with molecules of solvent. | 13. | Focus on observable substances or molecules themselves "dissolve". |
| 14. | Effects of heat on molecular motion | 14. | The only effect of heat on substances is to make its molecules move faster. | 14. | Molecules themselves can be hot or cold. |
| 15. | Molecular explanation of thermal expansion | 15. | Increased motion moves molecules farther apart. | 15. | Molecules themselves expand. |
| 16. | Spaces between molecules | 16. | Gases consist of nothing except molecules with empty spaces between them. | 16. | Molecules have "air" or other things between them. |
| 17. | Molecular explanation of states of matter | 17. | States of matter are due to different arrangements and motions of molecules:<br>-solids: vibrate in rigid array<br>liquids: random motion within liquid<br>gases: random motion, no limits | 17. | States of matter described only in terms of observable properties or properties of the state attributed to individual molecules (e.g., solid molecules are hard, liquid molecules are in drops, etc.). |

| Molecular level: Conceptions about molecules and their nature | | | |
|---|---|---|---|
| 18. | Molecular explanation of changes of state | 18. Heating and cooling cause changes of state by making molecules move faster or slower. | 18. Heating and cooling make molecules "melt", "evaporate", etc.; or molecules begin to move when heated. |
| 19. | Molecular explanation of evaporation | 19. Fast-moving molecules escape from liquid. | 19. Molecules "evaporate" or dissappear. |

and functions that they perform (e.g., gas exchange), systems of scientific knowledge also have structures (conceptions) and functions or activities for which they are used (tasks). An adequate description of any organ in the human body should include both its structure and its function. Similarly, an adequate description of an intended learning outcome should include both tasks or activities (cognitive functions) and the conceptions necessary to perform them (cognitive structures). For a more complete discussion of this analogy, see Anderson & Roth (1989).

A comparison between the conceptions listed in Table 3 and the concepts listed in Table 1 shows some important overlap in content. In particular, there is a good deal of similarity between the concepts in Table 1 and the molecular goal conceptions (numbers 10-19) on Table 3. Thus the essential conceptual content of the "Models of Matter" unit was retained, but the description of what students should learn in "Matter and Molecules" is more complete in two respects. First, the interviews and tests enabled us to describe typical patterns in student thinking before the beginning of instruction; these are described in the "Typical Naive Conception" column of Table 3. Thus Table 3 describes learning--desired changes in student thinking--rather than simply describing the knowledge that students should acquire.

The second difference between the concepts in Table 1 and the conceptions in Table 3 is also a result of the research on student conceptions. As we indicated above, many of the students' difficulties in performing the tasks resulted from misconceptions about the systems, which they were working with, that had nothing to do with molecules. Table 3 therefore has a section describing "macroscopic" issues where student conceptual change is necessary in

addition to the "molecular" issues that were the focus of the "Models of Matter" unit.

The tasks in Table 2 differ from science process in several important respects. First, the tasks are not generalizable skills (as science processes were supposed to be) but actions in which people engage by using their scientific knowledge. The performance of any task (such as explaining why the dime dances) requires both conceptual knowledge (about the gases, thermal expansion, molecular motion, and so forth) and procedural knowledge (about what to observe, how to describe it, how to develop an explanation, and so forth). The X's on Table 2 identify the conceptions that are particularly important and likely to be troublesome for sixth-graders trying to perform that particular task. (They do not identify all the knowledge that is necessary for the performance of the task.)

Just as there are general categories of process skills, we recognize general categories of tasks or functions of science. The categories are different, however, because they are based on different conceptions of what scientists do. Lists of science process skills emphasize experimentation for the purposes of developing new scientific knowledge as the central activity of science. Our categories of tasks or functions, on the other hand, emphasize the applications or <u>uses</u> or scientific knowledge in scientific or real world contexts. One consequence of this shift in emphasis is that explanation, which does not have a place on lists of science processes, can be seen as a legitimate--in fact central--function of scientific knowledge and the problem of what to do with the "explain" objectives is solved. (Our other functional categories are description, prediction, and control. See Anderson, 1987, or Anderson & Roth, 1989, for a more detailed discussion.)

Summary for developing goals. Developing descriptions of intended learning outcomes was an important activity early in the development of both the "Models of Matter" and the "Matter and Molecules" units. The two units were different, however, in the conceptual frameworks used to guide the development process, in the nature of the development process itself, and in the resulting descriptions of intended learning outcomes. The most important differences were the following:

1. The development process for the "Matter and Molecules" unit included an extensive program of research into how children thought about the unit content and performed the unit activities. This made it possible to describe intended learning as a set of conceptual changes that students needed to undergo, rather than simply as content to be learned.

2. Whereas the "Models of Matter" unit described learning outcomes as a set of interacting concepts and process skills, the "Matter and Molecules" unit described learning outcomes as a set of conceptual changes which students needed to undergo as they learned to perform scientific tasks.

3. Our research revealed that in order to perform the tasks successfully, students would have to master not only the molecular conceptions that were the focus of the "Models of Matter" unit, but also a set of macroscopic conceptions concerning the nature of substances and how they are affected by physical changes.

Developing Draft Materials

By the time that descriptions of intended learning outcomes were completed, the development teams for both units also had some preliminary ideas about activities to be included in the final unit. For the "Models of Matter" development team, these ideas took the form of lists of activities that might be included in each lesson cluster. The list for the lesson cluster that included the dancing dime activity is included in Figure 1. For the "Matter and Molecules" unit, the preliminary list consisted of the "Models of Matter" unit itself, which was to be modified into the new unit. For both units, the next step was to develop these preliminary ideas into draft materials that could be field-tested.

There were similarities in the broad outlines of the development processes for the two units. For both units, relatively large development teams helped to generate ideas that served as the basis for writing of the actual materials by one or two people. There were differences, however, in the composition of the development teams, in the nature of the development process, and in the draft materials that were produced. These differences are described below.

Developing draft materials for "Models of Matter." The development team for the "Models of Matter" unit included the four authors and the Houghton Mifflin Science editor. The authors were all professional science educators; three were university professors and the forth, a former science supervisor and editor for the SCIS program, was in the process of starting his own business. After the first list of possible activities had been developed by Berkheimer, the ideas for the unit were discussed at length by the development team and alternatives and modifications were discussed, until the team reached consensus about the outline of suggested activities.

In addition to generating activities that were interesting to students, the authors made use of an instructional model that guided the development of sequences of activities. They sequenced the lessons within each lesson cluster into five categories: introduction, development, enrichment, application, and evaluation. This sequence was a modification of the SCIS learning cycle--exploration, invention, and discovery. In the introduction (cf., exploration) the students usually did a hands-on activity in which they became familiar with a particular phenomenon and practiced one or more process skills. In the development activity (cf., invention) the introductory activity was reviewed, terms introduced, and concepts defined. Enrichment activities were optional activities designed to extend the development activity, giving the students additional opportunities to comprehend the concepts and processes involved.

The application activity (cf., discovery) was designed to give the students an opportunity to apply the major concepts that have just been developed in a similar but somewhat different context. The evaluation activity was designed to give the teachers some feedback on the extent to which the students learned the major concepts and processes developed in the lesson cluster.

The dancing dime activity occurs in the development portion of a lesson cluster that focuses on expansion and contraction. It is preceded by an activity on expansion of liquids in thermometers (introduction) and followed by activities involving expansion joints in bridges and railroad tracks (application). The final activity in the lesson cluster (evaluation) asks students to explain the expansion of a balloon placed over the mouth of a cold soda bottle that is warmed (the activity that was used in the clinical interview) and to explain why a heated metal ball will no longer slip through a close-fitting metal ring.

Once the lists of activities were generated, the writing of the unit was left in the hands of Berkheimer. Support from other members of the development team was limited to weekly meetings with one of the other authors. The draft materials were generally completed about a week before fieldtesting, so a complete draft of the unit was not available when fieldtesting began. The draft materials took the form of a combined student text and activity guide in dittoed form. Writing of the teacher's guide did not begin until after fieldtesting had been completed.[3]

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[3]The draft version of the dancing dime activity differed from the final version in two respects. It did not have the first paragraph explaining thermal expansion. It did contain, however, specific instructions to students to "explain your observations in terms of the small particle model" that were deleted from the final version of the unit. (The "small particle model" was the term used to describe kinetic molecular theory in the "Models of Matter" Matter" unit.)

Developing draft materials for "Matter and Molecules." The development team for "Matter and Molecules" was larger and more varied than the development team for "Models of Matter." It included three university professors (one chemistry professor and two science educators), three graduate students, four collaborating teachers, and undergraduate assistants. All of these people played important roles in the sequence of activities that led to the writing of draft materials for this unit.

Development of "Matter and Molecules" began with a careful analysis of teaching and learning in the "Models of Matter" unit. The four collaborating teachers taught the unit during the fall of Year 1. As described above, student learning was assessed through tests and clinical interviews administered both before and after instruction. In addition, the university professors and graduate students observed regularly as the collaborating teachers taught the unit, conducted informal interviews with the 24 target students (six in each class), and collected copies of the work of those students. The collaborating teachers discussed their teaching with the university staff members, who also kept journals describing their reactions to the activities in the unit and their assessments of the strengths and weaknesses of each activity.

These data collection activities made possible a fairly rich and detailed analysis of the strengths and weaknesses of the "Models of Matter" unit. The tests and clinical interviews provided data on how well the students understood each of the goal conceptions and how well they could perform each of the types of tasks on the Table 2 chart. These analyses also provided detailed descriptions of the difficulties that students encountered in trying to understand the unit content and assessments of the effectiveness of the unit in helping to overcome those difficulties (Eichinger, Anderson, Berkheimer, Blakeslee, in

press). The classroom observations and analyses of students' work provided information about how students interpreted particular activities and assignments. Finally, the discussions with the teachers and the teachers' journals provided insight from a teacher's point of view into the strengths and weaknesses of the text and the teacher's guide.

All of these analyses were discussed in detail by the development team in a series of meetings during the summer of Year 1. These meetings led to a number of decisions that determined the nature of the "Matter and Molecules" unit. For example, the development team decided that the new unit would consist of a separate student text (the Science Book) and an Activity Book, rather than the text alone as in the "Models of Matter" unit. There were also a number of substantial curricular revisions, most of which concerned lesson clusters other than the one on thermal expansion (Berkheimer, Anderson, & Spees, 1990). At the end of these meetings, the development team had produced a detailed lesson-by-lesson outline of the unit that guided the writing of the Science Book and the Activity Book.

Most of the writing of the Science Book and the Activity Book was done by the two science educators. In writing they were guided by the analyses of Year 1 teaching, the unit outline, an instructional model derived from work on science teaching for conceptual change (reviewed by Anderson & Smith, 1983) and by work on the social construction of knowledge in academic subjects and in everyday life (Collins, Brown, Newman, in press; Rogoff & Lave, 1984; Vygotsky, 1962; 1978). The model suggests that helping students to master difficult tasks such as those on Table 2 can be thought of as a five-step process (though in practice steps are often combined, see Anderson & Roth, 1989). The steps are as follows:

1. Establishing a problem: helping students to see that they will be working on interesting questions to which they do not yet know the answers.

2. Modeling: showing students how experts approach and solve the problem.

3. Coaching: providing students with opportunities for guided practice in solving the problem themselves usually with the help of "scaffolding," or organizing frameworks that provide temporary support while students are in the early stages of learning.

4. Fading: continuing practice in which the amount of support provided is gradually decreased.

5. Maintenance: providing opportunities to use the skills and concepts that students have developed in other contexts at other times.

This framework, together with the data from student tests and interviews and classroom observations provided the authors with very detailed guidance in the writing process. The results of this guidance can be seen in many aspects of the completed activity (see Appendix B).[4] The text contains more explicit explanatory material than "Models of Matter," for example, because the collaborating teachers, only one of whom had majored in science in college, found the step of modeling appropriate explanations very difficult with the minimal guidance provided by the "Models of Matter" text and teacher's guide. The reference to expansion and compression of gases in an earlier lesson cluster was a form of maintenance: The students are supposed to see how the contents of both lesson clusters fit together in a larger conceptual framework.

The admonition to "talk about both substances and molecules in your explanation" in Question 3 refers to a heuristic introduced seven lessons earlier. This heuristic was designed to help students (who had rarely been

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[4] Although a variety of editing changes were made between the draft version of the dancing dime activity and the final version in Appendix B, the only significant change involved adding question 4 to Activity 6.4 in the Activity Book.

called on to speak or write about science in entire sentences) produce coherent scientific explanations. The heuristic reminded students that good scientific explanations should (a) identify the substance that is changing and (b) explain the change in terms of molecules and their motions. Earlier lessons had contained examples of explanation in which statements about substances and molecules were explicitly identified (modeling) and questions for the students in which they were asked to write separate sentences about substances and about molecules (coaching with scaffolded tasks). By the time they reach the dancing dime activity, use of this heuristic has reached the "fading" stage: Students are reminded of the heuristic, but it is no longer used to structure their response to the question. In later lessons students are asked to explain phenomena without being reminded of the heuristic, but the teacher's guide suggests that the teacher use it as a criterion for grading. This structured sequence of activities is designed to help students internalize guidelines for developing explanations that they will then use even in the absence of explicit cues.[5]

Many of the questions in the Activity Book also resulted from the Year 1 data collection and analysis and from the discussions of the development team. Questions 1 and 4c in Activity 6.4, for instance, resulted from observations of student difficulties in class and in clinical interviews. Question 1 is intended to help students focus on the air inside the bottle as the substance

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[5] We do not claim that this particular heuristic (or any other guidelines explicit enough to be useful to sixth graders) is generalizable to all contexts where scientific explanations are called for, or that explaining phenomena is a generalizable skill. The heuristic did prove very useful in helping students who otherwise had no idea what they should say when they were asked to "explain" something in a scientific context. For discussions of students' difficulties in producing scientific explanations, see Hesse & Anderson (1988) and Solomon (1983).

that is changing, rather than thinking only about the bottle and the dime. Question 4c is designed to help the class deal with the common misconception that the dime dances and the balloon expands because "heat rises."

In addition to the Science Book and the Activity Book, the pilot materials for the "Matter and Molecules" unit included teacher's guides for both books. Substantial portions of the teacher's guides were written by two graduate students on the development team, Theron Blakeslee and Okhee Lee. The decision to write the teacher's guides before pilot testing and the content of the teacher's guides themselves both reflect a desire to develop materials that teachers could use as tools in their planning and teaching, rather than a set program that they would "implement." We thus viewed teacher's guides that help teachers to make informed, intelligent decisions about how to proceed within their particular classrooms as a critical part of the program, one that needed to be field-tested at least as carefully the instructional materials themselves.

Summary for development of draft materials. Development of the draft versions of the two units differed in a number of important respects. First, the development teams were different: The development team for "Matter and Molecules" was larger and more diverse, particularly in that it included collaborating teachers from the beginning of the process. Development of the "Matter and Molecules" unit was also guided by an extensive empirical data base on classroom teaching and student learning that had not been available to the developers of "Models of Matter." The use of these data was guided both by extensive discussions among members of the development team and by an instructional model built on constructivist and social constructivist theories of how people go through the process of conceptual change and master difficult tasks. A final important difference is that the teacher's guide for "Matter and

Molecules" was written before pilot testing, rather than after. The result was that the pilot materials tested for the "Matter and Molecules" unit contained considerably more information for both students and teachers. The materials were designed to help teachers and students through the difficult process of constructing scientific understanding.

Fieldtesting and Revision

After the first drafts were completed both units underwent cycles of fieldtesting and revision, leading to the final prepublication version. The fieldtesting phrases were different, however, with regard to the nature of the materials that were tested, the settings and data collection for the field tests, the criteria by which the pilot materials were judged, and the nature of the final products that emerged from the revision process. These differences are discussed below.

Fieldtesting and revision of "Models of Matter." As described above, the materials that were field-tested for "Models of Matter" consisted of a series of dittoed pages containing the text and directions for activities of the unit; there was no teacher's guide at the time of fieldtesting. The fieldtesting was done in a single classroom in an upper middle class suburban school district. The teacher in this classroom was a middle school teacher with a strong science background.

During the first period of each day, the author taught the unit while the teacher observed; then the teacher taught the unit herself during a later period and developed written comments for the author. In evaluating the activities, the author and the teacher were primarily interested in evaluating whether the activities were manageable and whether they generated student interest and discussion. There were no formal procedures for evaluating student learning either from individual activities or from the unit as a whole.

As discussed above (footnote 3), the revisions that resulted from this fieldtesting were relatively minor for the dancing dime activity. There was one major task to be completed after fieldtesting, however. The author had to write the teacher's guide. As can be seen in Appendix A, the teacher's guide included a variety of statements about intended learning, labeled "Process Skills," "Conceptual Content," "Purpose," and "Desired Learning Outcome." The development of these statements is discussed above. The teacher's guide also contained correct answers to the questions posed in the text and directions about how to prepare for and conduct the activity. The teacher's guide was not field-tested before it went to press.

Fieldtesting and revision of "Matter and Molecules." Fieldtesting of the "Matter and Molecules" unit was conducted by the four collaborating teachers in their own classrooms, using the relatively complete versions of the Science Book, Activity Book, and the teacher's guides that had been developed prior to the beginning of fieldtesting. During the pilot testing, data collection followed essentially the same pattern as it had the year before when the teachers were teaching "Models of Matter": clinical interviews, pretests, and posttests for students, classroom observations by project staff, discussions with the collaborating teachers, and journals kept by the collaborating teachers.

There were a number of ways in which this procedure made it possible to give the new unit a more realistic test than that given to "Models of Matter." More teachers and more students were involved and the science backgrounds of the teachers and socioeconomic status of the students were more representative of our society as a whole. Perhaps more important, the teachers were testing a reasonable approximation of the finished unit, rather than simply trying out the activities. They decided what to do by reading the text and teacher's

guide and planning their lessons (as teachers normally have to do), rather than by imitating what they had just seen the author do. Project staff were available and willing to help, but they helped by responding to requests from the teachers rather than by providing models for them to follow; the helpfulness of project staff generally did not take forms that rendered difficulties with the text or teacher's guide invisible. Thus the fieldtesting procedures made it possible to evaluate how well the full set of materials worked as tools to aid teachers in the process of planning and teaching.

The data collection procedures also made it possible to evaluate the draft materials according to a much larger and more realistic set of criteria. Most obviously, the clinical interviews (test analyses were not completed until after the final revisions) and classroom observations made it possible to develop detailed analyses of how the units had and had not helped students to change their conceptions. Classroom observations and student work also gave us some ideas about the quality of students' cognitive engagement, rather than simply of their interest and enthusiasm. Finally, the teachers' journals and discussions with other project staff gave us a clear idea of the technical and conceptual difficulties involved in planning and teaching the new unit and of the degree to which the materials and teacher's guide gave the teachers adequate support in their attempts to deal with those difficulties.

After the fieldtesting was complete, the entire project staff (professors, collaborating teachers, and graduate students) held another series of meetings to discuss the results of the fieldtesting and consider revisions. The result was a set of fairly detailed plans for revising the unit. These revisions were quite extensive for some lesson clusters, especially those on evaporation and condensation, but as discussed above (see footnote 4), they were relatively limited for the dancing dime activity.

A comparison between Appendix A and Appendix B reveals that there are important differences not only between the texts (discussed above) but also between the teacher's guides. Like the "Models of Matter" teacher's guide the two "Matter and Molecules" teacher's guides provided information about intended student learning, but the nature of the information provided reflects the differences in theories of learning that informed the two units. The goal and objectives listed at the beginning of the lesson cluster are somewhat more specific restatements of the tasks from the Tasks by Conceptions chart (Table 2). The description of conceptual learning is derived from our analyses of the tests and clinical interviews and attempts to describe the conceptual changes that students must go through to master the tasks described in the objectives. Finally, the portion of Table 3 that is most relevant to this lesson cluster is reproduced. Learning is thus portrayed to the teacher as a process of conceptual change.

The two teacher's guides are alike in that both provide fairly detailed teaching suggestions and answers to questions. The "Matter and Molecules" teacher's guide, however, is more likely to have comments that explain the purposes of activities in terms of conceptual changes in students or that help teachers to be alert for misconceptions that may be revealed in students' responses to questions. In general, the "Matter and Molecules" teacher's guides make more of an attempt to give cognitive rationales for teaching activities.

Summary of fieldtesting and revision. The process of fieldtesting and revision were substantially different for the two units and resulted in substantially different products. The "Models of Matter" unit was field-tested by its author and one collaborating teacher in an upper middle class suburban setting. Since there was no teacher's guide, the collaborating teacher watched

the author, then imitated him. The evaluation focus was on whether the activities generated student interest and class discussions. The teacher's guide was written later and never field-tested.

In contrast, the "Matter and Molecules" unit was field-tested by the collaborating teachers under conditions that were more like those normally encountered in teaching and that left many important professional decisions in the hands of the teachers. The criteria by which the success of the unit was judged were also more extensive, including the usefulness of the text and teacher's guide as tools for planning and teaching and their success in helping students achieve conceptual change. Like the student materials, the teacher's guides that resulted from this process were substantially different from their predecessors, particularly in that they portrayed expected student learning as involving conceptual change and in that they provided more extensive rationales for activities included in the unit.

## Comparing the Two Units

We have described a number of ways in which the "Matter and Molecules" unit is <u>different</u> from its predecessor, but is it <u>better</u>? During the project, we collected a variety of evaluative data that are relevant to this question. During Year 1, all the sixth-grade science teachers in the school district (15 teachers in all) taught the "Models of Matter" unit. Similarly, all 15 sixth-grade science teachers in the district taught the "Matter and Molecules" unit during Year 2. For purposes of comparison, the data reported below come from 12 teachers (the 4 collaborating teachers and 8 other teachers) who taught both years.

The eight teachers who were not collaborating teachers taught with little extra support from the project staff. A one-day workshop was conducted before

they began teaching the unit each year, and there was a collaborating teacher available for consultation in each school. The classes of the other eight teachers were not observed, there were no pretests, and there were no interviews. Posttests were administered upon completion of the unit each year, and at the end of Year 2 the teachers filled out a questionnaire and met with project staff to discuss their experiences in teaching the unit. It is these data that form the basis for the comparisons below.

Comparing Student Learning

A detailed discussion of student learning can be found in another paper (Lee, et al., in press), but some of the main results are briefly summarized below. Table 4 compares the average percentage of students who were classified as demonstrating understanding of the 19 goal conceptions (see Table 3) on the pretests and posttests each year. The pretest data come from the classes of the four collaborating teachers. The posttest data come from 15 classrooms (12 regular and 3 accelerated) taught by the 12 teachers who participated in both years of the study.

A fairly large number of students failed to achieve the rigorous criteria for understanding each year. (Students had to use goal conceptions successfully across several items involving description, explanation, or predication of natural phenomena to be classified as exhibiting understanding.) A number of patterns are nevertheless clear in the results. Achievement with the "Models of Matter" unit was higher than is typical when conceptual change tests are administered to classes that have used commercial materials (cf., Anderson & Smith, 1983; Blakeslee, Anderson, & Smith, 1986; Roth, 1984). This is particularly true for the conceptions involving thermal expansion (numbers 3, 14, and 15), indicating that the lesson cluster containing the dancing dime was one

TABLE 4

Percent of Students Inferred to Hold Goal Conceptions on Pre- and Posttests in Year 1 and Year 2

| Conception | | Comparison (%) | | | |
|---|---|---|---|---|---|
| | | Year 1 | | Year 2 | |
| | | Pre- | Post- | Pre- | Post- |
| 1. | Definition of matter | 1.0 | 9.1 | 1.9 | 25.5 |
| 2. | Conservation of matter | 9.90 | 21.4 | 7.5 | 66.5 |
| 3. | Thermal expansion | 10.9 | 67.7 | 17.9 | 79.7 |
| 4. | Nature of smells | 2.0 | 32.3 | 5.7 | 47.6 |
| 5. | Distribution of gasses in space | 4.0 | 26.3 | 6.6 | 62.7 |
| 6. | Compression of gasses | 2.0 | 15.9 | 0.9 | 36.5 |
| 7. | Water vapor in air | 1.0 | 7.4 | 0.9 | 40.0 |
| 8. | Condensation | 3.0 | 4.1 | 0.0 | 21.6 |
| 9. | Molecular constitution of matter | 11.9 | 40.8 | 8.5 | 63.8 |
| 10. | Size of molecules | 7.9 | 24.4 | 8.5 | 68.6 |
| 11. | Constant motion | 4.0 | 50.4 | 2.8 | 71.9 |
| 12. | Visibility of molecular motion | 5.0 | 47.9 | 3.8 | 70.3 |
| 13. | Molecular explanation of dissolving | 1.0 | 19.5 | 1.9 | 58.1 |
| 14. | Effects of heat on molecular motion | 4.0 | 45.5 | 1.9 | 66.2 |
| 15. | Molecular explanation of thermal expansion | 2.0 | 26.8 | 0.9 | 49.7 |
| 16. | Spaces between molecules | 0.0 | 26.8 | 1.9 | 44.1 |
| 17. | Molecular explanation of states of matter | 0.0 | 6.6 | 0.0 | 35.1 |
| 18. | Molecular explanation of changes of state | 1.0 | 14.2 | 0.9 | 34.6 |
| 19. | Molecular explanation of evaporation | 4.0 | 23.6 | 0.9 | 23.5 |
| | Average | 3.8 | 26.0 | 3.8 | 49.6 |

of the more successful lesson clusters in "Models of Matter." Achievement was substantially higher for almost every conception, however, when teachers used the "Matter and Molecules" unit during Year 2. Even during Year 2, however, many students were not achieving complete understanding; substantial improvement should not be confused with complete success.

Comparing Teachers' Reactions

Our data on teachers' reactions to the two units are far more informal and anecdotal than our data on student learning. They consist of questionnaire responses and transcripts of discussions with project staff that were not formally analyzed. Nevertheless, we wish to discuss some of the patterns that we saw in teachers' comments and illustrate them with excerpts from one of the discussions.

The first and most obvious pattern is that the teachers were uniformly enthusiastic in their comments about the "Matter and Molecules" unit and in their belief that it constituted a substantial improvement over "Models of Matter." In fact, we were somewhat surprised to hear such enthusiastic comments coming from a group of veteran inner-city teachers who had not always been positively inclined toward innovations introduced by college professors. Some more specific patterns in the teachers' comments are discussed below.

One thing that the teachers liked about the new unit was that they felt it was much more supportive of teachers who, like them, were trying to teach science without the benefit of strong science backgrounds. The following excerpt from a postteaching discussion both describes how they liked the "Matter and Molecules" unit and provides a commentary on the struggles of teachers who must try to teach topics that they feel less than completely certain about themselves.

T1: I thought the model explanations [of natural phenomena in the Science Book] were very well done. The fact that they don't assume that the students know a lot of things prior to the lesson, and more or less it made the students feel good about themselves. It didn't make them feel dumb. Here's the [old] text asking them a question and I have no idea what the question means. They [the new text] ask it in very simple terms and they understood it and I enjoyed it.

T2: I found it very helpful for me as a teacher also because I found myself trying to be very careful and not contradict, you know, what I want them to do and make the same mistakes myself. And so to have the model explanation right there for you, at the end of the activity, and after they've tried it themselves and you've heard their explanations when they discussed it with each other. Then they come out with the model. I think it helps them to hear it and also helped me to make sure that I was concluding correctly, you know, what was intended, because I can really go off.

T3: You know, it made you feel a little bit intelligent when you were trying to teach it. And so, this material, I had to read rather carefully and think through and I would have felt really poorly about it if I hadn't.

T1: That's right.

T3: But I knew it too, if I had something one way and then realized I needed you know, before I had really misconceived the whole thing myself. So I didn't really ever make those kinds of mistakes [with the new unit].

T1: One of the things I enjoyed about the unit, it helps the teacher feel good about herself or himself while teaching it.

T3: Right.

T1: You don't have to say, well, what does the book really want: What are they trying to say? Am I guessing right or guessing wrong?

A second notable pattern in the discussion was that several of the teachers saw the new unit as helping their students to be successful in cognitively complex tasks that had previously seemed too difficult for them and saw that even ordinary students were capable of complex scientific cognition:

T3: I had some kids who knew--one child who was in the third grade reading book, who had absolutely no self assurance. In the beginning of the thing, every question, he'd say, I don't know what it's asking. I don't know what to do. And I'd always say, what does the question ask you and sometimes he really couldn't [answer]. In the begin beginning, he wasn't sure of what he was reading. Once we got the question, then I'd start asking him questions that he would answer, so he'd say, alright, you know.

But by asking him questions and after doing this for about four lessons constantly, finally he got it in his head enough so he was doing it, which is a pretty good result for what you were trying to get at. But there's a lot of fear at first for that particular child.

T2: The students talked about this unit amongst themselves outside of science and at home more than anything I've ever taught.

T3: Well, I had one child who is kind of smart come back with an explanation from her father on the difference between steam and water vapor, and you know, in the beginning, we had that backwards and so forth. And I copied him part of the page was in the back. . . .

I: Part of the teacher's guide.

T3: And so I kind of found that and I copied that, and gave it to the student and said maybe it's a matter of semantics or something. And I had another boy who broke his arm. While he was in the doctor's office, looked at the clock and said, "Mrs. M. is probably talking about molecules." His mother's up here thinking how upset he is and everything and so they did get into that.

T1: I think a lot of the students enjoyed it. Not only the fact that it was an experiment, but that they could talk it over within their group.

T2: I agree with that. Not only the fact that it's an experiment, because I've done experiments before, but to really have them sequence like this and all tie together, you know, it just seemed more meaningful that I was aimed toward a goal and it wasn't haphazard as the old textbook [Houghton Mifflin Science]. It went off in different directions.

Finally, although we were concerned about the length and the amount of information in the teacher's guide, the teachers reported reading it with care and being intrigued by the idea that their students' learning involved a process of conceptual change, as illustrated in the following excerpt:

I: OK, let's talk about teacher's guide. We need to move along here.

T3: I'm just saying one word. It was fantastic.

T1: It was. It was excellent. I loved it. I started reading it and I said, I'm going to get bored, but I found myself interested in it which was good. Because usually I fall asleep.

I: So, like, even the introductions at the beginning of it and so forth were useful?

T1: Yeah.

T3: Uh huh.

T1: It was very useful.

I: That's interesting.

T1: One thing that I did, which I thought was helpful for me as well as the students, where you had the issue, the goal conceptions and the student conceptions, I copied this. I copied enough for half of the classroom and then they sat together in twos, and they read it through, they looked over it, they looked at the issue, the goal conceptions, and a lot of student conceptions and then we discussed it.

I: So you actually used that with the students for your teaching. How did that work?

T1: I think the students enjoyed it and I think it helped me too, to see where they were coming from, and it helped them to see where their thinking was and to look at the way they should think or the conception that they should have.

The teachers did not perceive the new unit as being without problems. They reported, for example, that they spent much more time planning and grading than they did with other units, and some teachers doubted that they would be able to sustain that level of effort over the entire school year. But in the short term, at least the teachers all seemed to feel that their investment of extra time and energy was rewarded with student learning, student enthusiasm, and enhanced professional growth.

## Conclusions

Although this paper focuses on quite specific contrasts between two instructional units, its purpose is to raise a set of more general issues concerning our current technology for curriculum development. Although other commercial and National Science Foundation (NSF)-sponsored programs differ from Houghton Mifflin Science in many particulars, we see in them very few examples of successful solutions to the problems that bedeviled the authors of Houghton Mifflin Science. In fact the percentage of students mastering the goal

conceptions in Year 1 of this study was the highest that we have ever seen for conceptual change learning from commercial or NSF-sponsored programs (cf., Anderson and Smith, 1983; Blakeslee, Anderson, and Smith, 1986; Roth, 1984).

The last decade has seen a revolution in our research-based understanding of the processes of planning, teaching, and learning in science classrooms. This research-based understanding has been accompanied by a growing realization that even the best of our current programs are failing to develop real understanding in most students. Many of the people currently engaged in science curriculum development are aware of this research and cognizant of its importance. And yet, they are generally unable to use the research to its full potential because they lack a technology of curriculum development--a set of procedures for developing objectives, writing and field-testing materials--that utilizes the insights from recent research. In fact, there are few important differences between curriculum development techniques being used today and those that prevailed during the 1960s and 1970s.

The purpose of this paper is to demonstrate that workable alternative procedures for curriculum development do in fact exist and can be used in typical classroom contexts. These procedures, which are based on recent advances in research on teaching and learning, involve changes in many aspects of the curriculum development process. They involve developing statements of intended learning outcomes that reflect a more current understanding of the relationship between thought and action and portray learning as a process of conceptual change. They involve procedures for writing, field-testing, and revision that make extensive use of empirical data about teachers' planning, classroom processes, and student learning. The result has been the development of materials that are substantially better than their predecessors in terms of both student conceptual change and teachers' feelings of professional efficacy.

We do not mean to imply, of course, that we have all the answers. In fact, we can see many deficiencies in the "Matter and Molecules" unit as it now exists and we have failed to take full advantage of other advances such as those in research on cognitive strategy learning or in information-processing technology. In a way, though, that is not the point. We do not claim to have made the curriculum development process "scientific," but we have found ways to make it more disciplined and better informed than previously, a little more like engineering and a little less like seat-of-the-pants tinkering than in the past.

This and other new models of curriculum development are not inexpensive. Developing "Matter and Molecules" required more resources than developing "Models of Matter" or comparable commercial units (though not more resources than were spent on the development of NSF-sponsored programs such as SCIS and SAPA). Furthermore, these resources were used to produce qualities in the finished product that did not particularly enhance its marketability ("Models of Matter" still <u>looks</u> better than its successor). We do believe, however, that the time has come to recognize the important roles that research on teaching and research on student cognition could play in curriculum development. In the long run, society would benefit from the investment in the curriculum materials developed with the benefit of our new knowledge.

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APPENDIX A*

"MODELS OF MATTER" DANCING DIME LESSON

1. INTRODUCTION TO LESSON CLUSTER

2. DANCING DIME LESSON

*NOTE The material in Appendix A is used with permission from the Houghton Mifflin Company, One Beacon Street, Boston, MA 02108 and is taken from C.F. Berger, Glenn D. Berkheimer, Harold T. Neuberger, & L.E. Lewis, Jr. (1979). Houghton Mifflin Science Program 1-6.

# Teaching Strategy

LESSON CLUSTER

B-2

## Heat Affects Matter

Objectives

[redacted]

[redacted]

■ *Introduction*

**(1) Heating and Cooling a Liquid**

***Process Skills Emphasized***
Observing, Applying

***Conceptual Content***
Liquids expand when heated and contract when cooled.

Particles of matter move faster when the matter is heated.

★ *Development*

**(2) Warming Air**

***Process Skills Emphasized***
Observing, Describing, Investigating, Applying

***Conceptual Content***
Particles of a gas move faster and usually farther apart when heated.





● *Application*

**(3) Bridges and Tracks**

***Process Skills Emphasized***
Observing, Applying

***Conceptual Content***
Particles of a solid will move faster and usually farther apart when heated.

△ *Enrichment*

***Process Skills Emphasized***

***Conceptual Content***

*Evaluation*

Wrap Up

**(4) Expansion and Contraction**

The students show that they have learned by using the small particle model to explain expansion and contraction in gases and solids.

## Warming Air

Matter changes when it is heated or cooled. Sometimes matter takes up more space. That is, it expands. Sometimes it takes up less space. That is, it contracts. Use a bottle to see what happens when a gas is heated.

Put an empty bottle in the refrigerator until it becomes cold.

Wet the rim of the cold bottle, and place a dime on it. Make sure that the space between the dime and the rim is wet enough to seal the opening.

Wrap your hands around the bottle to warm it. As the bottle becomes warm, it warms the air inside it.

*What happens as the air becomes warm?* ▲

Because of evidence from many investigations, scientists believe that particles of matter move farther apart when matter is heated.

▲ Dime moves up and down and makes a noise.

1. Does warm air take up more, less, or the same amount of space as cold air? How can you tell?
2. Did the air expand or contract?
3. Explain how this happens.

1. More. When the bottle was warmed, air came out of it.
2. Expanded.

3. When a gas is heated, the particles move faster and farther apart. So the gas expands.

193
★

### PURPOSE

To demonstrate and explain the expansion of a gas in terms of the small particle model.

### ADVANCE PREPARATION

The empty soda bottles should be the kind that have pry-off lids. Bottles with screw-tops tend to have necks too large to hold dimes on top. The bottles should be cold at the beginning of the activity. You can store them in a school refrigerator or in a styrofoam chest with some ice. If the weather is quite cold, the bottles can be left outdoors overnight for use the next day. Or, if the sun is out, place bottles with dimes in place in a sunny window.

### TEACHING SUGGESTIONS

1. Introduce this activity by reviewing the students' observations of the expansion and contraction of liquids and have them explain these observations in terms of the small particle model.
2. Now challenge the students to predict what will happen if a gas is heated. (The glass of the bottle also expands when warmed, but far less than the trapped air.)
3. Have them read page 193. Then demonstrate the placement of a dime on a bottle and emphasize the need to have an airtight seal. This is why the dime should be wetted with water. (If the water seal isn't sufficient, try saliva.)
4. Have the students work in groups of five, allotting one bottle and dime to a group for experimentation.
5. After students have had time to perform and observe the activity, have them write out their answers to the questions at the end of the page.
6. Discuss the student answers to the questions, allowing any explanations for what happens as long as the explanations fit the evidence. Be aware that some students may interpret expansion in terms of the particles themselves expanding rather than the spaces between particles expanding.
7. Especially stress parts 5 and 6 of the small particle model in the discussion: particles of matter move faster when the matter is heated, and particles of matter usually move farther apart when the matter is heated.

### DESIRED LEARNING OUTCOME

The students should be able to explain the expansion of a gas in terms of the smal particle model.

*Materials: Please see page T–333.*

APPENDIX B*

"MATTER AND MOLECULES" DANCING DIME

1. INTRODUCTION TO LESSON CLUSTER

2. SCIENCE BOOK STUDENT PAGES AND TEACHER'S GUIDE PAGES

3. ACTIVITY BOOK STUDENT PAGES AND TEACHER'S GUIDE PAGES

*Material from Appendix B taken from Berkheimer, Anderson, Lee, and Blakeslee (1988) and from Berkheimer, Anderson, and Blakeslee (1988).

# INTRODUCTION TO LESSON CLUSTER 6
## Heating and Cooling, Expansion and Contraction

A. Lesson Cluster Goals and Lesson Objectives

Goals:

Students should be able to explain why solids dissolve faster in hot water, and why substances expand when heated.

Lesson Objectives:

Students should be able to:

6.1 Explain why hard candy dissolves faster in hot water than in cold water.

6.2 Explain the expansion and contraction of solids.

6.3 Explain the expansion and contraction of liquids.

6.4 Explain the expansion and contraction of gases.

B. Key Elements of a Good Explanation

Both the rate of dissolving and thermal expansion can be explained by using the principle that molecules of a substance move faster when the substance is heated. In dissolving, molecules of hot water are moving faster than molecules of cold water, and hence break off molecules of candy faster. The molecules of candy that are knocked loose then mix in with the water molecules.

In thermal expansion, molecules of solids, liquids, and gases move farther apart when they move faster. When the molecules move farther apart, the solids, liquids, and gases get bigger.

C. Conceptual Learning

Several tasks in this lesson cluster deal with the conception of thermal expansion in three different states of matter. A principle applies to explain all the tasks: heating a substance makes the molecules of the substance move faster, and therefore they move farther apart. This makes the substance expand. In contrast, when a substance is cooled, things happen in the opposite way. Many students have difficulty understanding and applying this rule to explain phenomena.

First, the explanation of thermal expansion requires knowledge about molecules. Unless students understand this principle in molecular terms, their explanations may be inconsistent across different situations. For instance, the same student may think that a ball will shrink when heated, the column of mercury in a thermometer will rise because of heat pressure, and the dime on a bottle will rattle because hot air rises. They should understand that even though things "appear" different, the scientific conception of thermal expansion applies in all these situations.

Second, students may be confused between observable properties of substances and properties of molecules themselves. For instance, students may think that molecules become hot or cold, or that molecules themselves expand causing substances to expand. Students should realize that molecules do not get hot or cold and that the only change is to the motion and arrangement of molecules when a substance is heated or cooled.

Finally, students may have difficulty recognizing the cause/effect relationship. Students should understand that when molecules move faster, this causes the molecules to move farther apart. Then, students should associate what is happening to molecules with the change in the substance: When molecules move farther apart, this causes the substance to expand.

Lesson 6.1: Another Way to Make Something Dissolve Faster

This lesson explains why sugar dissolves faster in hot water: Molecules of hot water move faster and hit the molecules of sugar more often. Some students may think that "hot" molecules in hot water move faster than "cold" molecules in cold water. The teacher should stress that there is no change in individual molecules, but only in the motion of molecules.

Lesson 6.2: Heating Solids

This lesson explains the thermal expansion of solids. At the macroscopic level, some students may predict that solids "shrivel up" or shrink when heated. They should realize that solids actually expand when heated. At the molecular level, common students' misconceptions are:

a. Molecules themselves expand or contract.

b. Molecules do not move in solids (e.g., the metal) and begin to move when solids are heated.

c. Heat is made of "heat molecules."

Lesson 6.3: The Thermometer

This lesson explains thermal expansion of liquids, using the liquid in a thermometer as an example. At the macroscopic level, many students may think that the liquid comes out of the bulb and moves up (that is, the liquid changes places from the bottom toward the top) or that "heat pressure" of the hot water causes the liquid to go up. The teacher should emphasize that the liquid expands, not moves from place to place.

Lesson 6.4: Gases and the Dancing Dime

The expansion of air is illustrated by "The Dancing Dime" on top of a cold pop bottle. The explanation of the "dancing" is sometimes difficult for students. At the macroscopic level, some students may focus their attention on the bottle, the dime, heat, etc. They should first recognize what substance to focus on: the air in the bottle. Even then, many students may think using the idea of "heat" or "hot air": Hot air rises, heat rises, air pushes up, hot air pushes out the cold air, etc. All these ideas suggest that air moves from one place to another place within the bottle, rather than that air expands.

At the molecular level, some students may be confused between observable properties of substances and properties of molecules. For instance, they may think that molecules of air are cold and do not move when the bottle is frozen and that they begin to move when the bottle is heated.

D. Conceptual Contrasts

The chart below contrasts common patterns in student thinking with scientific thinking about some of the important issues for this lesson cluster.

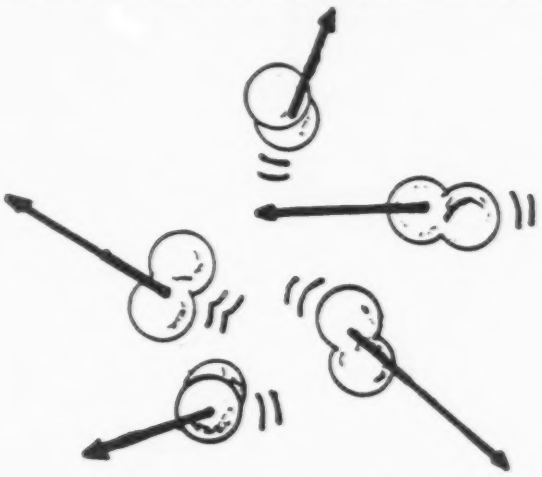
| Issue | Goal Conceptions | Students' Conceptions |
|---|---|---|
| Thermal expansion | Substances expand when heated. | Substances may "shrivel up" when heated; expansion of gases explained in terms of movement of air. |
| Constant motion | Molecules are constantly moving. | Molecules may sometimes be still, especially in solids. |
| Visibility of molecular motion | Molecular motion continues independently of observable movement. | Molecules simply share in observable movements of substances. Molecules do not move in solids. |
| Effect of heat on molecular motion | Molecules of hot substances move faster. | Molecules themselves can be hot or cold. |
| Molecular explanation of thermal expansion | Increased motion moves molecules farther apart. | Molecules themselves expand. |

Lesson 6.4: Gases and the Dancing Dime

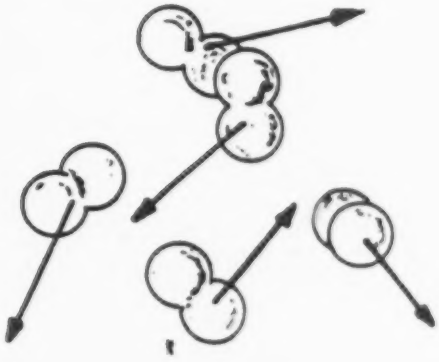
Solids expand when they are heated and contract when they are cooled. So do liquids. It probably won't surprise you that gases act the same way. Gases also expand when they are heated and contract when they are cooled.

The molecules of a hot gas move faster than the molecules of a cold gas, so they hit each other harder and bounce harder off the sides of a container. This makes the molecules move farther apart and push the sides of a container outward.

Cooling is just the opposite. The molecules slow down, so they don't hit each other or the walls of a container as hard, and they move closer together.



*Hot gases have fast-moving molecules that bounce farther apart*



*Cold gases have slow-moving molecules that stay closer together*

## Lesson 6.4: Gases and the Dancing Dime

### Purpose:

To help students use the kinetic molecular theory to explain the expansion and contraction of gases.

### Advance Preparation:

Collect one large glass soda bottle that has a pry-off cap for each student group. Bottles with screw-tops tend to have necks too large to hold dimes on top. The bottles should be cold at the beginning of the activity. You can store them in the school refrigerator or in a styrofoam chest with ice.

### Materials List:

1. One large soda bottle, cold
2. One dime
3. One balloon for optional activity

### Teaching Suggestions:

The expansion of gases is often confused with convection currents, especially in the activities we use that seem to show hot air rising. Watch out for this conceptual confusion. Students are very familiar with the phrase "hot air rises," and it seems difficult to picture gases (or solids, for that matter) expanding. The activity in this lesson will help students get a visual image of air expanding, especially if the class talks specifically about the difference between "hot air rising" and air expanding (see Activity Book, Lesson 6.4, question 4, especially part c).

Do you remember when you studied expansion and compression of gases in Lesson Cluster 4? Now you know <u>two</u> ways of moving the molecules of a gas closer together or farther apart!

In Lesson Cluster 4 you moved the molecules of gases closer together by pushing them together with pressure from something like a syringe or a bicycle pump. Another way to move the molecules closer together is to cool off the gas. Then the molecules slow down and move closer together even without an extra "push."

In Lesson Cluster 4 you moved the molecules of gases farther apart by releasing pressure, like when you released the plunger of the syringe or let the air out of the bicycle tire. Another way to move the molecules farther apart is to heat the gas. Then the molecules move faster and push each other farther apart.

Let's try that other way of getting gases to expand. The dancing dime will help you see it happen!

* * * * * * * *

Do Activity 6.4 in your Activity Book

* * * * * * * *

This lesson cluster is almost over. You knew before this lesson cluster that all substances are made of tiny particles called molecules. You knew that molecules are always moving.

In this lesson cluster you learned another important idea. The <u>temperature</u> of a substance tells you something about how fast the molecules are moving. Heating a substance makes the molecules move faster. Cooling a substance makes molecules move slower.

The motion of the molecules explains why solids dissolve faster in hot water, as well as thermal expansion and contraction. In Lesson Cluster 7 you will use these ideas about molecular motion to explain melting and freezing.

* * * * * * * *

Do Review Question Set 6.4 Now

* * * * * * * *

There is an Activity 6.4 and a Question Set 6.4.

Students should complete Activity 6.4: The Dancing Dime, at this time.

You may want to use Question Set 6.4: Lesson Cluster Review, as an assessment of student progress.

## Activity 6.4: The Dancing Dime

1. Your teacher will give you an empty soda bottle from the refrigerator. The bottle isn't <u>really</u> empty, though. What substance is inside it? _____

   Do you think that substance is hot or cold? _____

2. Wet the rim of the bottle and place a dime on it. Make sure that the space between the dime and the rim is wet enough to seal the opening so that nothing can get in or out. Wrap your hands around the bottle to warm it. What happened?

_____

_____

_____

3. Can you explain what happened? Talk about both substances and molecules in your explanation.

_____

_____

_____

4. Instead of placing a dime on the rim of a cold soda bottle, my friend placed a balloon over the rim.

   a. What do you think would happen to the balloon as the bottle got warm? _____

   b. Use molecules in your answer to explain what happened to the balloon. _____

_____

_____

   c. My friend said that if you turn the soda bottle upside down, the balloon would get smaller. Was my friend right? _____

   Use what you know about molecules to explain your answer.

_____

_____

Activity 6.4: The Dancing Dime

Teaching Suggestions:

This activity will work only if the dime forms a tight seal at the top of the bottle. It needs to be wet around the edges to do this.

Student Responses:

1. Air
   Cold

2. The dime jumped or danced.

3. When the air inside the bottle is heated it expands because the molecules of air move faster and hit each other harder. This pushes the molecules farther apart. The expanding air pushes on the dime and forces its way out of the bottle. This makes the dime jump or dance.

   Note: A good optional activity is to place a balloon on a large, cold soda bottle. As it warms up the balloon will inflate. Challenge the students to explain this change by using the kinetic molecular theory.

4. a. The balloon would get larger or expand.

   b. When the air inside the bottle was heated it expanded because the molecules of air moved faster, hit each other harder, and moved farther apart.

      (Some students explain what happens by saying that "heat rises." But the air in the bottle does not move upwards, it only expands and a small amount of air moves out of the opening. Those students who say that "heat rises" will probably be surprised if they tried this activity with the bottle upside down.)

   c. No. The molecules move in all directions, not just up. The molecules throughout the bottle and balloon moved faster, hit each other harder, and moved farther apart.

Question Set 6.4: Lesson Cluster Review

1. Try to summarize the main points of this lesson cluster by answering the two questions below. Talk about substances and molecules in each answer.

   a. What happens when substances are heated?

_____

_____

_____

   b. What happens when substances are cooled?

_____

_____

_____

2. In the ball and ring experiment, my friend figured out a good way to get a hot ball through a cold ring. He heated the ring! Explain why his method worked.

_____

_____

_____

3. Is it correct to say that heat makes the molecules of a substance expand?

   Why or why not? _____

_____

_____

4. If you want something to dissolve fast, should you mix it with hot

   water or cold water? _____ Why? _____

_____

_____

_____

Question Set 6.4: Lesson Cluster Review

Student Responses:

1. a. When substances are heated they expand because their molecules move faster, hit each other more often and push each other farther apart. The empty space between the molecules becomes larger, causing the substances to expand.

   b. When substances are cooled they contract because their molecules slow down, hit each other less often and move closer together. The empty spaces between the molecules become smaller, causing the substances to contract.

2. When you heat the ring it expands and the hole in the ring becomes larger, allowing the ball to go through. The ring expands because when it is heated its molecules move faster, hit each other more often, and push each other farther apart.

3. No. The molecules themselves do not expand or contract. They only move faster or slower.

4. Hot water. The molecules of the hot water are moving faster than the molecules of cold water. The faster the molecules move the more often they will hit the substance and the faster they will knock off molecules of the substance. The hot water will, therefore, dissolve a substance faster than cold water.